Device-Specific Power Delivery Network (PDN) Tool 2.0 User Guide

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This user guide provides a brief overview of the various tabs in the device-specific PDN tool 2.0. You can quickly and accurately design a robust power delivery network with the PDN tool 2.0. This is done by calculating an optimum number of capacitors that meet the target impedance requirements for a given power supply.

Note: The PDN tool 2.0 only supports Microsoft Excel 2007 and newer, and either US or UK English language.

Table 1: PDN Tool 2.0 Software Verification

Altera® has tested and verified that the PDN tool 2.0 is compatible with these platforms and software versions.

Operating System	Excel Versions
Windows 8 (32-bit)	2007, 2010, 2013
Windows 8 (64-bit)	2010, 2013
Windows 7 (32-bit)	2007, 2010, 2013
Windows 7 (64-bit)	2010, 2013
Windows XP	2007, 2010

Overview

The Altera PDN tool 2.0 helps PCB designers estimate the number, value, and type of decoupling capacitors needed to develop an efficient PCB decoupling strategy. It allows you to do this during the early design phase, without going through extensive pre-layout simulations.

The PDN tool 2.0 is a Microsoft Excel-based spreadsheet that calculates an impedance profile based on your input. For a given power supply, the spreadsheet only requires basic design information to calculate the impedance profile and the optimum number of capacitors to meet the desired impedance target (Z_{TARGET}). Basic design information includes the board stackup, transient current information, and ripple specifications, for example. The tool also provides device- and power rail-specific PCB decoupling cut-off frequency ($F_{EFFECTIVE}$). The results obtained through the PDN tool 2.0 are intended only as a preliminary estimate and not as a specification. For an accurate impedance profile, Altera recommends a post-layout simulation approach using any available EDA tool, such as Sigrity PowerSI, Ansoft SIWave, Cadence Allegro PCB PI, and so on.

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The device families supported by the Altera device-specific PDN tool 2.0 are shown at the top of the **Release Notes** tab and they include:

- Arria® 10
- Arria V
- Arria II GZ
- Cyclone® V
- Cyclone IV E
- Cyclone IV GX
- Stratix® V
- MAX® 10

PDN Decoupling Methodology Review

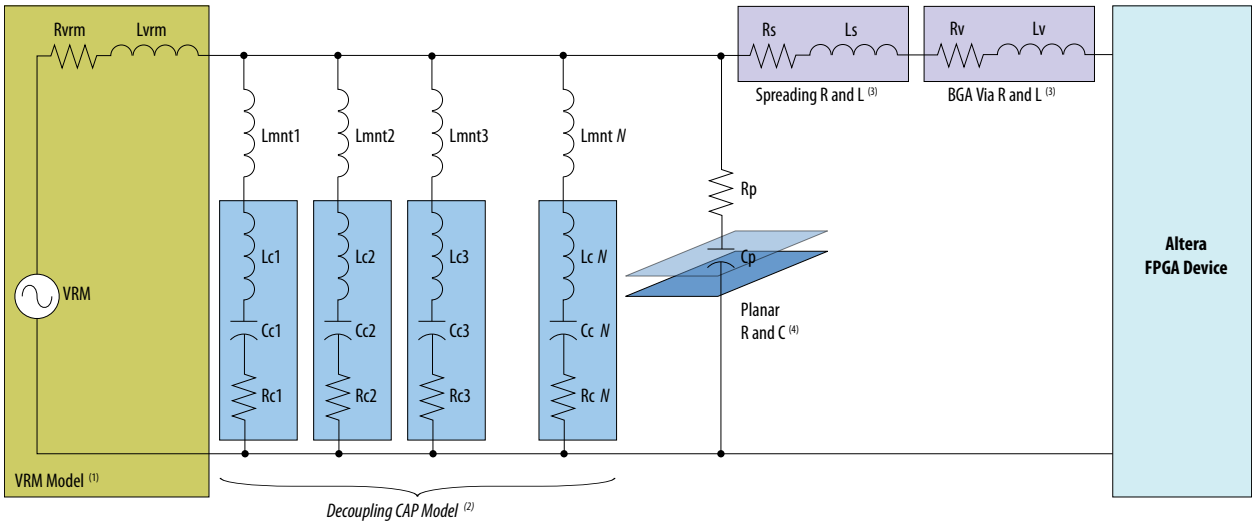
The PDN tool 2.0 provides two parameters for guiding PCB decoupling design: Z_{TARGET} and $F_{EFFECTIVE}$.

PDN Circuit Topology

The PDN tool 2.0 is based on a lumped equivalent model representation of the power delivery network topology.

Figure 1: PDN Topology Modeled as Part of the Tool

The PDN impedance profile is the impedance-over-frequency looking from the device side.



Notes:
1. You can define or change VRM parameters in the Library sheet of the PDN tool.
2. You can define or change Decoupling CAPs parameters in the Cap Mount, X2Y Mount, and Library sheets of the PDN tool.
3. Rs and Ls are parasitic capacitances and inductances from BGA balls and PCB traces and connections.
4. Represents PCB layers dedicated to power and ground planes.

For first order analysis, the VRM can be simply modeled as a series-connected resistor and inductor as shown above. The VRM has a very low impedence and can respond to the instantaneous current requirements of the FPGA in the following circumstances:

- At low frequencies up to approximately 50 KHz
- Depending on the voltage regulation module you use

The equivalent series resistance (ESR) and equivalent series inductance (ESL) values can be obtained from the VRM manufacturer. At higher frequency, the VRM impedance is primarily inductive, making it incapable of meeting the transient current requirement.

PCB decoupling capacitors are used for reducing the PDN impedance up to 100-150 MHz. The on-board discrete decoupling capacitors provide the required low impedance. This depends on the capacitor-intrinsic parasitics (R_{cN}, C_{cN}, L_{cN}) and the capacitor mounting inductance (L_{mntN}). The inter-planar capacitance between the power-ground planes typically has lower inductance than the discrete decoupling capacitor network, making it more effective at higher frequencies up to 150 MHz. As frequency increases, the PCB decoupling capacitors become less effective. The limitation comes from the parasitic inductance seen with respect to the FPGA. FPGA parasitic inductance includes capacitor mounting inductance, PCB spreading inductance, ball grid array (BGA) via inductance, and packaging parasitic inductance. All of these parasitics are modeled in the PDN tool 2.0 to capture the effect of the PCB decoupling capacitors accurately. To simplify the circuit topology, all parasitics are represented with lumped inductors and resistors despite the distributed nature of PCB spreading inductance.

Z_{TARGET}

According to Ohm's law, voltage drop across a circuit is proportional to the current flow through the circuit, and impedance of the circuit. The dynamic component of PDN current gives rise to voltage fluctuation within the PDN, which may lead to logic and timing issues. You can reduce excessive voltage fluctuation by reducing PDN impedance. One design guideline is target impedance, Z_{TARGET}. Z_{TARGET} is defined using the maximum allowable die noise tolerance and dynamic current change, and is calculated as follows.

Figure 2: Z_{TARGET} Equation

$$Z_{TARGET} = \frac{\text{Voltage Rail} \times \left(\frac{\text{Die Noise Tolerance\%}}{100}\right)}{\text{Maximum Dynamic Current Change}}$$

For example, to reliably decouple a 1.8-volt power rail that allows 5% of die noise tolerance and a maximum 2 A current draw, 50% of which is dynamically changing, the desired target impedance is calculated as follows.

Figure 3: Z_{TARGET} Example Equation

$$Z_{TARGET} = \frac{1.8 \times 0.05}{2 \times 0.5} = 0.09\,\Omega$$

To accurately calculate the Z_{TARGET} for any power rail, you must know the following information:

- The maximum dynamic current change requirements for all devices in the system that are powered by the power rail under consideration. You can obtain this information from manufacturers of the respective devices. You can calculate the maximum dynamic current change of a device using the maximum total current and the dynamic current change percentage.

  Note: The dynamic current change is intended to parameterize the high-frequency current draws required to provide the energy for CMOS transistors changing state. In the case of the core rail, the transients are generated by switching inside the FPGA core. Thus, a design which involves extensive logical switching generates higher % transients (dynamic current change) than a more static design. For information about recommended settings, refer to the table in the **Introduction** tab of the PDN tool 2.0.

  Note: You can obtain accurate estimations on the maximum total current for Altera devices using the *Altera PowerPlay Early Power Estimator (EPE)* tool or the Quartus® II PowerPlay Power Analyzer tools.
- The maximum allowable die noise tolerance on the power rail is given as a percentage of the supply voltage.

Device switching activity leads to transient noise (high frequency spikes) seen on the power supply rails. This noise can cause functionality issues if they are too high. The noise must be damped within a range defined as a percentage of power supply voltage. The recommended values for the maximum allowable AC die noise tolerance are listed in the **Introduction** tab of the PDN tool 2.0. Different rails have different specifications because of their sensitivity to the transient voltage noise as well as how much current is used by the power rail.

This AC die noise tolerance differs from the minimum and maximum voltage specifications in the device datasheet in that the voltage specifications in the device datasheet are DC values. The (DC) ripple of the voltage regulator module (VRM) is the change in the power supply voltage level. Altera devices are designed to operate within a specific voltage range, which is considered the DC specification. The DC specification is, in turn, translated to the requirement for the VRM ripple specification. This DC specification is not included in the die noise tolerance field in the PDN tool 2.0.

Refer to the **Introduction** tab of the PDN tool 2.0 for more information about Z_{TARGET}.

Table 2: Settings for the Arria 10 Device Power Rails

This information is from the PDN tool 2.0 for an Arria 10 device.

Rail Name [1]	Voltage (V)	Die Noise Tolerance (%)	Dynamic Current Change (%)	Description
VCC	0.85 - 0.9	5	50	Core
VCCIO	1.2 - 3.0	5	100	I/O Bank
VCCPT	1.8	5	50	I/O Pre-Drivers
VCCPGM	1.2/1.5/1.8	5	50	Programming Power

[1] For more information about power rail functions, refer to the Pin Connection Guidelines for the selected device family.

Rail Name [1]	Voltage (V)	Die Noise Tolerance (%)	Dynamic Current Change (%)	Description
VCCERAM	0.95	5	50	Programmable Power Tech Aux
VCCBAT	1.2/1.5/1.8	5	100	Battery Back-up Power Supply
VCCA_PLL	1.8	5	10	PLL (Analog)
VCCA_FPLL	1.8	5	10	FPLL
VCCR_GXB	0.9/1.0/1.1	3	30	XCVR RX (Analog)
VCCT_GXB	0.9/1.0/1.1	2	60	XCVR TX (Analog)
VCCA_GXB	0.9/1.0/1.1	5	10	XCVR /CDB (Analog)
VCCH_GXB	1.8	3	15	XCVR I/O Buffer Block
VCCR_GTB	0.9/1.0/1.1	3	30	28 Gbps XCVR RX (Analog)
VCCT_GTB	0.9/1.0/1.1	2	60	28 Gpbs XCVR TX (Analog)
VCCP	0.9	5	33	Periphery Supply Voltage

Related Information

- **Altera PowerPlay Early Power Estimator (EPE)**
- **Arria 10 GX, GT, and SX Device Family Pin Connection Guidelines.**
- **MAX 10 Device Family Pin Connection Guidelines.**
- **Stratix V E, GS, and GX Device Family Pin Connection Guidelines.**
- **Stratix V GT Device Family Pin Connection Guidelines.**
- **Arria V GT, GX, ST, and SX Device Family Pin Connection Guidelines.**
- **Arria II Device Family Pin Connection Guidelines.**
- **Cyclone V Device Family Pin Connection Guidelines.**
- **Cyclone IV Device Family Pin Connection Guidelines.**

[1] For more information about power rail functions, refer to the Pin Connection Guidelines for the selected device family.

$F_{EFFECTIVE}$

As previously illustrated, a capacitor reduces PDN impedance by providing a least-impedance route between power and ground. Impedance of a capacitor at high frequency is determined by its parasitics (ESL and ESR). For a PCB-mount capacitor, the parasitics include not only the parasitic from the capacitors themselves but also those associated with mounting, PCB spreading, and packaging. Therefore, PCB capacitor parasitics are generally higher than those of on-package decoupling capacitor and on-die-capacitance. Decoupling using PCB capacitors becomes ineffective at high frequency. Using PCB capacitors for PDN decoupling beyond their effective frequency range brings little improvement to PDN performance and raises the bill of materials (BOM) cost.

To help reduce over-design of PCB decoupling, this release of the PDN tool provides a suggested PCB decoupling design cut-off frequency ($F_{EFFECTIVE}$) as another guideline. It is calculated using the PCB, package, and die parasitics. You only need to design PCB decoupling that keeps Z_{EFF} under Z_{TARGET} up to $F_{EFFECTIVE}$.

Refer to *Troubleshooting Z_{EFF}* if the Z_{EFF} is too high or the number of capacitors for decoupling becomes too high.

Note: $F_{EFFECTIVE}$ may not be enough when the Altera FPGA device shares a power rail with another device. The noise generated from other devices propagates along the PDN and affects FPGA device performance. The frequency of the noise is determined by the transfer impedance between the noise source and the FPGA device, and can be higher than $F_{EFFECTIVE}$. Reducing PDN parasitic inductance and increasing the isolation between the FPGA device and noise source reduces this risk. You must perform a transfer impedance analysis to clearly identify any noise interference risk.

Related Information

- **Troubleshooting ZEFF** on page 27
- **For more information about the PDN decoupling methodology behind the Altera PDN design tool, refer to the Power Distribution Network Design Using Altera PDN Design Tools online course.**

Major Tabs of the PDN Tool 2.0

The tabs at the bottom of the PDN tool 2.0 application help you calculate your impedance profile.

Table 3: PDN Tool 2.0 Tabs

Tab	Description
Release_Notes	Provides the legal disclaimers, the revision history of the tool, and the user agreement.
Introduction	Displays the schematic representation of the circuit that is modeled as part of the PDN tool 2.0. It also provides the following related information: • a quick start instruction • recommended settings for some power rails • a brief description of decoupling design procedures under different power supply connection schemes

Tab	Description
System_Decap	The principal tab that allows you to decouple your system. It displays by default when you launch the application. This tab provides an interface to enter your power sharing scheme for a selected FPGA device and derive the decoupling based on the input.
Stackup	Provides an interface to enter your stackup information into the PDN tool.
Library	Points to various libraries (capacitor, dielectric materials, and so on) that are called by other tabs. You can change the default values listed as part of these libraries.
BGA_Via	Provides an interface to calculate the BGA mounting inductance based on design-specific via parameters and the number of vias.
Plane_Cap	Provides an interface to calculate the plane capacitance based on design-specific parameters.
Cap_Mount	Provides an interface to input design-specific parameters for calculating the capacitor mounting inductance for two different capacitor orientations (Via on Side [VOS] and Via on End [VOE]).
X2Y_Mount	Provides an interface to input design-specific parameters for calculating the capacitor mounting inductance for X2Y type capacitors.
Enlarged_Graph	Provides an enlarged view of the Z-profile shown in the **System_Decap** tab.

System_Decap

You can determine the decoupling of selected FPGA devices based on the power sharing scheme entered in the **System_Decap** tab.

The **System_Decap** tab is divided into the following sections:

- Device selection
- Power rail data and configuration
- VRM Data
- Rail group summary
- VRM Impedance
- BGA Via
- Plane
- Spreading
- $F_{EFFECTIVE}$
- Decoupling selection
- Result summary

Device Selection Section

1. Select the **Family/Device** using the pull-down list.
2. Select your device from the **Available Devices** pull-down list.
3. Select your desired power rail configuration from the **Power Rail Configuration** pull-down list.

The pull-down selections are based on examples from the pin connection guidelines for the device. Select the closest one to your design, and use it as a basis for entering your design data. Refer to the pin connection guidelines for your device on the Altera website.

The tool updates the list of power rails and the contents in the power rail configuration sections based on your selections.

Figure 4: Device Selection

Related Information

- **Arria 10 GX, GT, and SX Device Family Pin Connection Guidelines.**
- **MAX 10 Device Family Pin Connection Guidelines.**
- **Stratix V E, GS, and GX Device Family Pin Connection Guidelines.**
- **Stratix V GT Device Family Pin Connection Guidelines.**
- **Arria V GT, GX, ST, and SX Device Family Pin Connection Guidelines.**
- **Arria II Device Family Pin Connection Guidelines.**
- **Cyclone V Device Family Pin Connection Guidelines.**
- **Cyclone IV Device Family Pin Connection Guidelines.**

Power Rail Data and Configuration Section

This section of the application is divided into two areas. Area 1 is for the device power rail information, and Area 2 is for the power rail configuration.

1. Enter the power supply voltage in the **Voltage** column for each power rail listed in Area 1 by selecting a value from the pull-down menu, or by manually entering your own value.

   Note: You must enter the total current consumption of related power rails before you can use the system decoupling function.

   You can optionally adjust the recommended number up or down slightly based on knowledge of the intended application.
2. Enter the current consumption in the **I max** column for each power rail.
   The earliest data from the *Altera PowerPlay Early Power Estimator (EPE)* can provide good values for the current entries. The EPE delivers bulk data for the transceiver channels. Each bank of transceiver channels should be assigned the total EPE value divided by the number of banks. Later in the design cycle, the Quartus II Power Play Power Analyzer (PPPA) can derive much better data for each bank rail.
3. Setup your device power sharing scheme in Area 2.

Figure 5: Power Rail Data and Power Sharing Scheme Section

This configuration is an example of how this section of the spreadsheet should look. Every design will vary slightly.

		Group #	1	2	3	4	5
		Regulator / Separator	switcher	linear	linear	switcher	filter
		Parent Group	none	none	none	none	4
Rail	Voltage	I max					
VCC	0.9	69	x				
VCCA_PLL	1.8	1					x
VCCBAT	1.8	0.05				x	
VCCERAM	0.9	1	x				
VCCH_GXBL	1.8	5					x
VCCH_GXBR	1.8	5					x
VCCIO2A	1.8	1				x	
VCCIO2I	1.8	1				x	
VCCIO2J	1.8	1				x	
VCCIO2K	1.8	1				x	
VCCIO2L	1.8	1				x	
VCCIO3A	1.8	1				x	
VCCIO3B	1.8	1				x	
VCCIO3C	1.8	1				x	
VCCIO3D	1.8	1				x	
VCCIO3E	1.8	1				x	
VCCIO3F	1.8	1				x	
VCCIO3G	1.8	1				x	
VCCIO3H	1.8	1				x	
VCCP	0.9	1	x				
VCCPGM	1.8	1				x	
VCCPT	1.8	1				x	
VCCR_GXBL1C	1.1	3		x			
VCCR_GXBL1D	1.1	3		x			
VCCR_GXBL1E	1.1	3		x			
VCCR_GXBL1F	1.1	3		x			
VCCR_GXBL1G	1.1	3		x			
VCCR_GXBL1H	1.1	3		x			
VCCR_GXBL1I	1.1	3		x			
VCCR_GXBL1J	1.1	3		x			
VCCR_GXBR4F	1.1	3		x			
VCCT_GXBL1C	1.1	3			x		
VCCT_GXBL1D	1.1	3			x		
VCCT_GXBL1E	1.1	3			x		
VCCT_GXBL1F	1.1	3			x		
VCCT_GXBL1G	1.1	3			x		
VCCT_GXBL1H	1.1	3			x		
VCCT_GXBL1I	1.1	3			x		
VCCT_GXBL1J	1.1	3			x		

Area 1

Area 2

Each column in Area 2 represents a power group in your system. Add or remove a power group using the **Add Group** or **Remove Group** buttons. The first row of each group is the **Regulator/Separator** type. Set the source type for the power group and available options from the pull-down list as **switcher**, **linear**, or **filter**.

The second row is the **Parent Group** type. The available options for this row are **None** and the number representing all listed power groups. Input your power sharing hierarchy in this column, and set the power rail connection using the remaining rows.

Note: The PDN tool 2.0 defines the power rail configuration using the **Parent/Child** power group. A power group is a child power group if it attaches to another power group. The other power group is the parent group in this case. A parent group can have multiple child groups. A parent power group number is required for the child group. The parent group number of a parent power group is assigned to **None** because the group has no parent group.

The available options are:

- " " — Device rail does not connect to the power group.
- **x** — Device rail connects to the power group.
- **x/related**— Device rail connects to the group, and its activity is related to other rails that connect to the same group. You must select **x/related** if that VCCIO/VCCPT power rail is related to other rails within the same power rail group.

Note: Two IO rails are related if their output activities are synchronous. For example, when two VCCIO rails are assigned to the same memory interface. The maximum current will usually be reached at the same time for these related rails. As a result, the total current of related rails equals the sum of the current of all shared rails. The total current of unrelated rails is calculated using the root-mean-square (RMS) method.

The PDN tool 2.0 sets the default power rail sharing configuration based on the selected Altera-recommended power rail configuration listed above. Make changes to better match your design.

Related Information

Altera PowerPlay Early Power Estimator (EPE)

VRM Data Section

Enter the voltage regulator module (VRM) parameters for **DC supply voltage** at **Switcher VRM Efficiency** and **Switcher VRM Input Current**.

Rail Group Summary Section

In this section, you can find a list of the following calculated key parameters of all power groups:

- Voltage
- Total Current
- Dynamic Current Change
- Die Noise Tolerance
- Core Clock Frequency
- Current Ramp Up Period
- Z_{TARGET}

These options allow you to customize how the data is collected or analyzed.

The **Dynamic Current Change** parameter has a pull-down menu with the following options:

- Calculate
- Override

Dynamic current change percentage requires a lot of diligence. The EPE and PPPA both deliver values for current usage that include:

- the maximum static current (does not vary)
- the maximum current usage by the active elements

This calculation yields both a very high total current and a fairly high dynamic current usage. Calculations for a value to insert into the **Dynamic Current Change** field could yield a value much lower than the auto-populated value, which represents a safe engineering value.

The **Die Noise Tolerance** parameter has a pull-down menu with the following options:

- Calculate
- Override

Some PDN tool variants allow you to add data for the **Core Clock Frequency** and **Current Ramp Up Period** parameters using the pull-down menus. These values tell the tool how to calculate the current ramp up period for transient events, sometimes reducing transient current changes. The values relate to how fast the clock for the section is running, and the length of the data pipeline. Given a transient change in the input data, there are clock cycles in the pipeline for the algorithm to deliver the results. If the input data change activates a broad yet short pipeline, the transient is abrupt. This results in a large current change for the number of logic elements being used. If the pipeline is narrow and long, the overall change in current usage is proportionately smaller.

You can set the **Core Clock Frequency** parameter to a **High**, **Medium**, **Low**, or **Custom** set of input frequencies. The **Custom** option allows you to enter a specific input frequency.

The **Current Ramp Up Period** parameter allows you to specify the number of clock cycles consumed by the pipeline. You can select a **High**, **Medium**, **Low**, or **Custom** setting. Altera recommends using a smaller value unless you have already entered a complete design in Quartus II and determined the precise value.

VRM Impedance Section

Enter the VRM impedance values for the regulators. Use the pull-down menu to enter data for **VRM Resistance** and **VRM Inductance**.

There are three ways to change the voltage regulator module (VRM) parameters. Depending on what you select in the **VRM Impedence** pull-down menu, you can:

- Select **Custom** and set your desired Rvrm and Lvrm values.
- Select **Library** and get the suggested typical Rvrm and Lvrm values. This depends on the type of regulator (for example, switching, linear, or filter) you have selected.
- For switching regulators, you can choose a specific Enpirion® VRM (based on ordering code) directly in the pull-down menu.

You can use the PowerPlay Early Power Estimator (EPE) to help select the appropriate Enpirion VRM module to use for each power supply in your system.

BGA Via Section

In the **BGA Via** table shows the L and R values per via. You can set the tool to **Calculate**, **Custom**, or **Ignore**. For a fully customized workflow in which each rail group can have different settings:

1. Select the **System_Decap** tab in the PDN tool 2.0.
2. Set the total effective R and L values in the **BGA Via** section to match your system.

Setting the **BGA Via** table to **Calculate** or **Ignore** causes the **System_Decap** tab to use the same global settings for all rail groups.

Plane Section

In the **Plane** table, you can set the tool to **Calculate**, **Custom**, or **Ignore**. For a fully customized workflow in which each rail group can have different settings:

1. Select the **Plane_Cap** tab in the PDN tool 2.0.
2. Set the parameters to match your system, and notice that the **Total planar capacitance** and **Total sheet resistance** values are updated automatically .
3. In the **System_Decap** tab, select the **Custom** option for each group where a custom plane is required.
4. Enter the calculated **Ctotal** and **Rtotal** values into the **Plane** section of the **System_Decap** tab.

Setting the **Plane** table to **Calculate** or **Ignore** causes the **System_Decap** tab to use the same global settings for all rail groups.

Spreading Section

In the **Spreading** table, you can set the tool to one of the following options:

- **Ignore**
- **Low**
- **Medium**
- **High**
- **Custom**

For a fully customized workflow in which each rail group can have different settings:

1. Select the **Library** tab in the PDN tool 2.0.
2. Set the parameters in the **Spreading R and L** table to match your system.
3. Examine the range of spreading R and L values to determine if you need a custom R and L. If a custom R and L is warranted, select **Custom** in the **System_Decap** tab and set the R and L values directly.

Setting the **Spreading** table to **Low**, **Medium**, **High**, or **Ignore** causes the **System_Decap** tab to use the same global settings for all rail groups.

$F_{EFFECTIVE}$ Section

You can set **Feffective** to **Calculate** or **Override.** Select the **Calculate** option to use the Altera recommended cut off frequency based on package and die parasitics.

Decoupling Section

You can set **Decoupling** to **Manual** or **Auto**. If you select the **Auto** option, any change you make to the system is automatically reflected in the decoupling solution. You can also view the impedance chart per rail group or VRM.

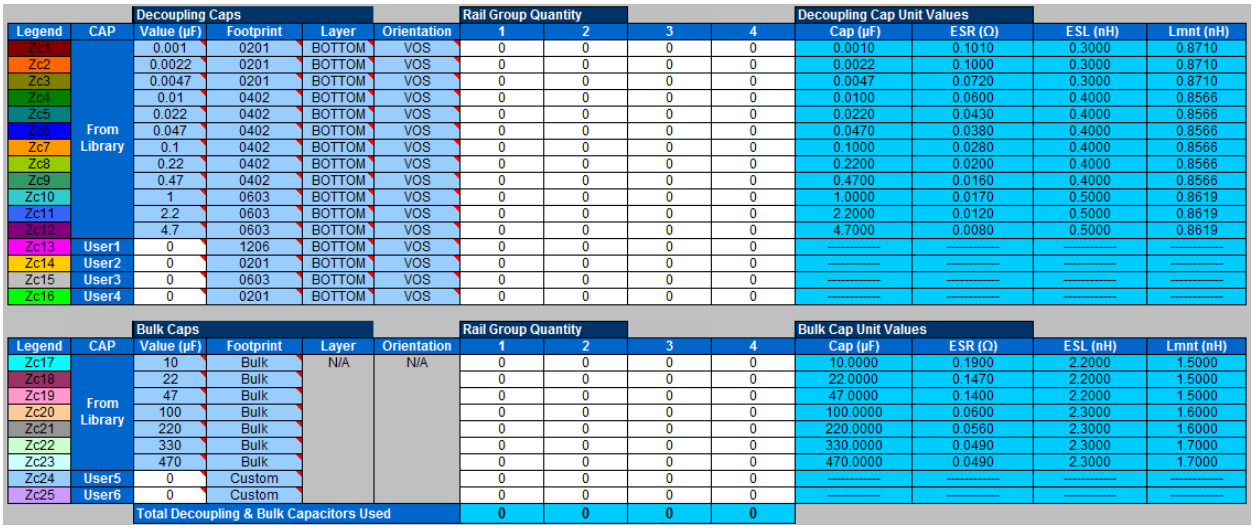
Selecting the **Manual** option allows you to:

- Lock in calculated decoupling solutions from being further optimized by any changes made to the **System_Decap** tab.
- Add or remove the number and type of decoupling capacitors in the **Results Summary** section. You can see its immediate impact on the impedance profile curve.

Results Summary Section

You can find the list of the number and type of capacitors used for each group, and the summary of all the capacitors used. The values in each column indicate the number of capacitors needed of each value for each rail.

Figure 6: Results Summary Section of the System_Decap Tab



		Decoupling Caps				Rail Group Quantity				Decoupling Cap Unit Values			
Legend	CAP	Value (µF)	Footprint	Layer	Orientation	1	2	3	4	Cap (µF)	ESR (Ω)	ESL (nH)	Lmnt (nH)
Zc1	From Library	0.001	0201	BOTTOM	VOS	0	0	0	0	0.0010	0.1010	0.3000	0.8710
Zc2		0.0022	0201	BOTTOM	VOS	0	0	0	0	0.0022	0.1000	0.3000	0.8710
Zc3		0.0047	0201	BOTTOM	VOS	0	0	0	0	0.0047	0.0720	0.3000	0.8710
Zc4		0.01	0402	BOTTOM	VOS	0	0	0	0	0.0100	0.0600	0.4000	0.8566
Zc5		0.022	0402	BOTTOM	VOS	0	0	0	0	0.0220	0.0430	0.4000	0.8566
Zc6		0.047	0402	BOTTOM	VOS	0	0	0	0	0.0470	0.0380	0.4000	0.8566
Zc7		0.1	0402	BOTTOM	VOS	0	0	0	0	0.1000	0.0280	0.4000	0.8566
Zc8		0.22	0402	BOTTOM	VOS	0	0	0	0	0.2200	0.0200	0.4000	0.8566
Zc9		0.47	0402	BOTTOM	VOS	0	0	0	0	0.4700	0.0160	0.4000	0.8566
Zc10		1	0603	BOTTOM	VOS	0	0	0	0	1.0000	0.0170	0.5000	0.8619
Zc11		2.2	0603	BOTTOM	VOS	0	0	0	0	2.2000	0.0120	0.5000	0.8619
Zc12		4.7	0603	BOTTOM	VOS	0	0	0	0	4.7000	0.0080	0.5000	0.8619
Zc13	User1	0	1206	BOTTOM	VOS	0	0	0	0	----------	----------	----------	----------
Zc14	User2	0	0201	BOTTOM	VOS	0	0	0	0	----------	----------	----------	----------
Zc15	User3	0	0603	BOTTOM	VOS	0	0	0	0	----------	----------	----------	----------
Zc16	User4	0	0201	BOTTOM	VOS	0	0	0	0	----------	----------	----------	----------

		Bulk Caps				Rail Group Quantity				Bulk Cap Unit Values			
Legend	CAP	Value (µF)	Footprint	Layer	Orientation	1	2	3	4	Cap (µF)	ESR (Ω)	ESL (nH)	Lmnt (nH)
Zc17	From Library	10	Bulk	N/A	N/A	0	0	0	0	10.0000	0.1900	2.2000	1.5000
Zc18		22	Bulk			0	0	0	0	22.0000	0.1470	2.2000	1.5000
Zc19		47	Bulk			0	0	0	0	47.0000	0.1400	2.2000	1.5000
Zc20		100	Bulk			0	0	0	0	100.0000	0.0600	2.3000	1.6000
Zc21		220	Bulk			0	0	0	0	220.0000	0.0560	2.3000	1.6000
Zc22		330	Bulk			0	0	0	0	330.0000	0.0490	2.3000	1.7000
Zc23		470	Bulk			0	0	0	0	470.0000	0.0490	2.3000	1.7000
Zc24	User5	0	Custom			0	0	0	0	----------	----------	----------	----------
Zc25	User6	0	Custom			0	0	0	0	----------	----------	----------	----------
		Total Decoupling & Bulk Capacitors Used				0	0	0	0				

Recommended Flow for Deriving Decoupling for FPGA System using the System_Decap Tab

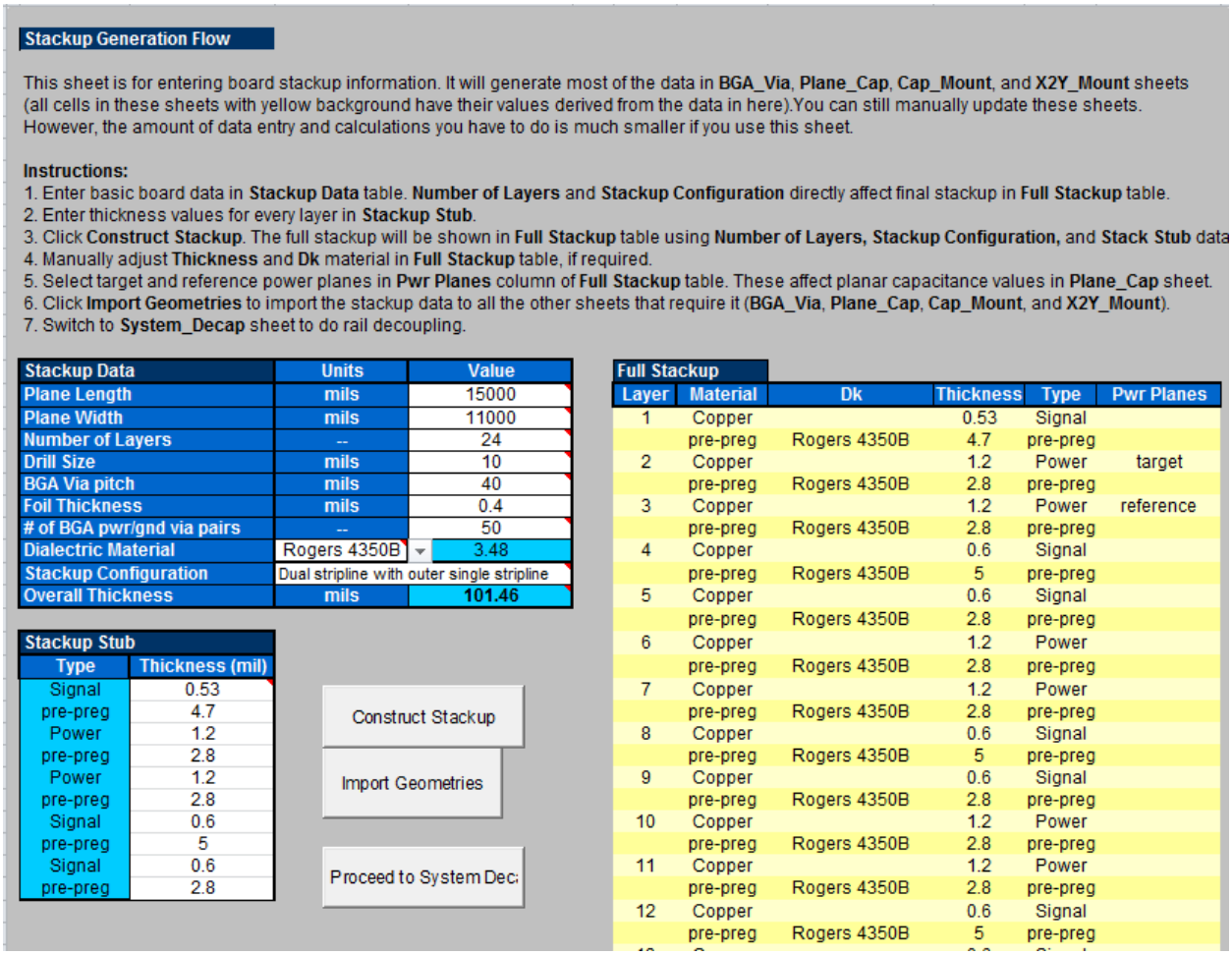
To use the **System_Decap** tab, perform the following steps:

1. Select the Altera device family or device.
2. Set up the stack up information in the **Stackup** tab.
3. Select the decoupling scheme.
   The tool updates the power rail connection configuration to the scheme recommended in the Pin Connection Guidelines.
4. Ensure that the following default parameters match your system, and make the necessary changes such as:
   - power rail configuration
   - relativity of power rails within the same power group
   - power group layer
   - number of power/ground Via pairs
   - DC voltage supply for VRM module
   - decoupling cap location
5. Enter the projected current consumption of each power rail.
   If you applied the **Custom** setting, refer to **BGA Via Section** on page 11, **Plane Section** on page 11, or **Spreading Section** on page 12 to enter your values.

Stackup

Enter the PCB stackup information of your design in the **Stackup** tab. This tab updates related data in the **BGA_Via**, **Plane_Cap**, **Cap_Mount** and the **X2Y_Mount** tabs. The stackup information in this tab is also used for the **System_Decap** tab. Follow the instructions provided at the beginning of the tab to fill in the content for this tab.

Figure 7: Stackup Tab



Stackup Generation Flow

This sheet is for entering board stackup information. It will generate most of the data in **BGA_Via**, **Plane_Cap**, **Cap_Mount**, and **X2Y_Mount** sheets (all cells in these sheets with yellow background have their values derived from the data in here).You can still manually update these sheets. However, the amount of data entry and calculations you have to do is much smaller if you use this sheet.

Instructions:
1. Enter basic board data in **Stackup Data** table. **Number of Layers** and **Stackup Configuration** directly affect final stackup in **Full Stackup** table.
2. Enter thickness values for every layer in **Stackup Stub**.
3. Click **Construct Stackup**. The full stackup will be shown in **Full Stackup** table using **Number of Layers, Stackup Configuration,** and **Stack Stub** data
4. Manually adjust **Thickness** and **Dk** material in **Full Stackup** table, if required.
5. Select target and reference power planes in **Pwr Planes** column of **Full Stackup** table. These affect planar capacitance values in **Plane_Cap** sheet.
6. Click **Import Geometries** to import the stackup data to all the other sheets that require it (**BGA_Via**, **Plane_Cap**, **Cap_Mount**, and **X2Y_Mount**).
7. Switch to **System_Decap** sheet to do rail decoupling.

Stackup Data	Units	Value
Plane Length	mils	15000
Plane Width	mils	11000
Number of Layers	--	24
Drill Size	mils	10
BGA Via pitch	mils	40
Foil Thickness	mils	0.4
# of BGA pwr/gnd via pairs	--	50
Dialectric Material	Rogers 4350B	3.48
Stackup Configuration	Dual stripline with outer single stripline	
Overall Thickness	mils	101.46

Stackup Stub	
Type	Thickness (mil)
Signal	0.53
pre-preg	4.7
Power	1.2
pre-preg	2.8
Power	1.2
pre-preg	2.8
Signal	0.6
pre-preg	5
Signal	0.6
pre-preg	2.8

Construct Stackup

Import Geometries

Proceed to System Dec

Full Stackup

Layer	Material	Dk	Thickness	Type	Pwr Planes
1	Copper		0.53	Signal	
	pre-preg	Rogers 4350B	4.7	pre-preg	
2	Copper		1.2	Power	target
	pre-preg	Rogers 4350B	2.8	pre-preg	
3	Copper		1.2	Power	reference
	pre-preg	Rogers 4350B	2.8	pre-preg	
4	Copper		0.6	Signal	
	pre-preg	Rogers 4350B	5	pre-preg	
5	Copper		0.6	Signal	
	pre-preg	Rogers 4350B	2.8	pre-preg	
6	Copper		1.2	Power	
	pre-preg	Rogers 4350B	2.8	pre-preg	
7	Copper		1.2	Power	
	pre-preg	Rogers 4350B	2.8	pre-preg	
8	Copper		0.6	Signal	
	pre-preg	Rogers 4350B	5	pre-preg	
9	Copper		0.6	Signal	
	pre-preg	Rogers 4350B	2.8	pre-preg	
10	Copper		1.2	Power	
	pre-preg	Rogers 4350B	2.8	pre-preg	
11	Copper		1.2	Power	
	pre-preg	Rogers 4350B	2.8	pre-preg	
12	Copper		0.6	Signal	
	pre-preg	Rogers 4350B	5	pre-preg	

Stackup Data

The **Stackup Data** section is where you enter board dimension data and other parameters, such as board stackup settings, power via, and dielectric material.

Stackup Stub

The content in this section is updated based on the settings in **Stackup Configuration**, in the **Stackup Data** section. Enter the thickness of the metal/dielectric material for each layer. The stackup shown in this section is used as the basic unit to construct the complete PCB stackup.

Full Stackup

This section lists the complete stackup of your board. You can modify content in the section to better match your board design. The last column in the section is the **PWR plane** types. In a single rail analysis case, assign the layer where the power rail is located as **target**, and the ground layer that the power rail refers to as **reference**.

Table 4: Full Stackup Buttons

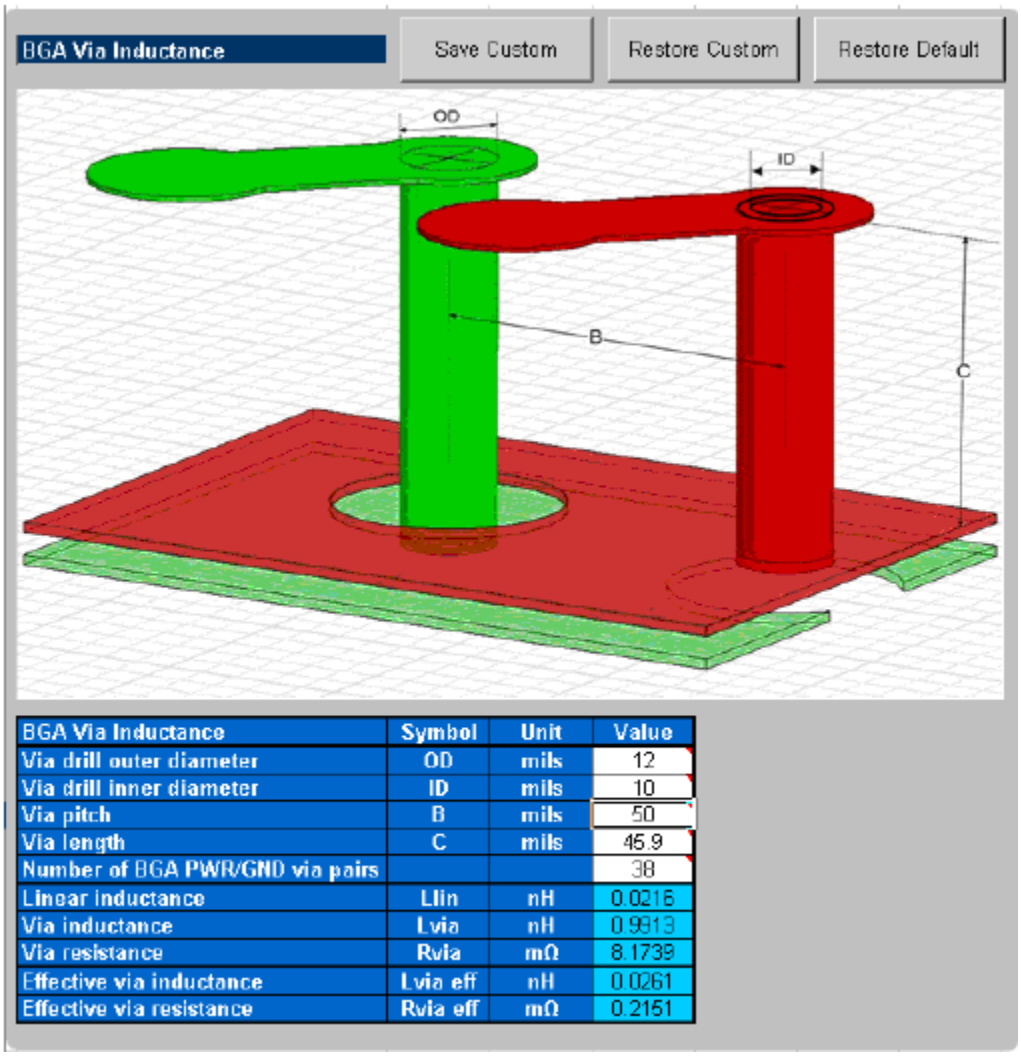
Button Label	Description
Construct Stackup	Populates the **Full Stackup** section to the number of layers defined in the **Stackup Data** section using the blocks listed in the **Stackup Stub** section.
Import Geometries	Updates geometry parameters in the **BGA_Via**, **Plane_Cap**, **Cap_Mount**, and **X2Y_Mount** tabs using your input from the **Stackup Data** section. The tool also checks that the **PWR Planes** column in the **Full Stackup** section has only one target layer, and provides a warning for this error.
Proceed to System Decap	Opens the **System_Decap** tab.

BGA_Via

The **BGA Via** tab calculates the vertical via loop inductance under the **BGA pin** field.

Figure 8: BGA_Via Tab

The values in the **Unit** column indicate a unit value per one pair.



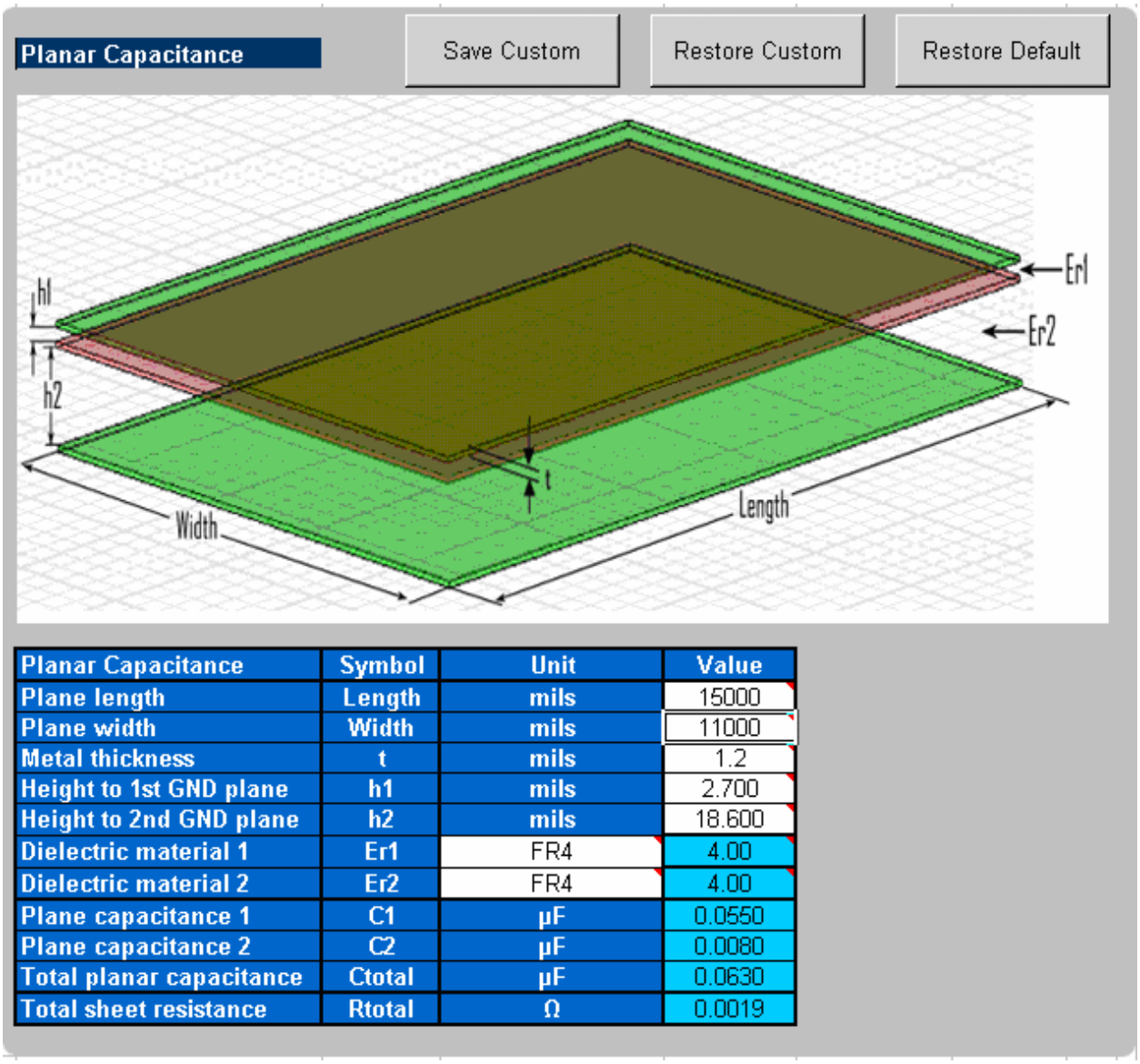
BGA Via Inductance	Symbol	Unit	Value
Via drill outer diameter	OD	mils	12
Via drill inner diameter	ID	mils	10
Via pitch	B	mils	50
Via length	C	mils	45.9
Number of BGA PWR/GND via pairs			38
Linear inductance	Llin	nH	0.0216
Via inductance	Lvia	nH	0.9813
Via resistance	Rvia	mΩ	8.1739
Effective via inductance	Lvia eff	nH	0.0261
Effective via resistance	Rvia eff	mΩ	0.2151

Enter the layout-specific information such as via drill diameters, via length, via pitch, and the number of power/ground via pairs under the BGA in the **BGA Via Inductance** table. The tool calculates the effective via loop inductance and resistance value. You can save the change made to the tab, restore the changes, or restore the tab back to the default settings.

Plane_Cap

The **Plane Cap** tab calculates the distributed plane capacitance in microfarads (µF) that is developed between the power/ground planes based on the parallel plate capacitor equation.

Figure 9: Plane_Cap Tab



Planar Capacitance	Symbol	Unit	Value
Plane length	Length	mils	15000
Plane width	Width	mils	11000
Metal thickness	t	mils	1.2
Height to 1st GND plane	h1	mils	2.700
Height to 2nd GND plane	h2	mils	18.600
Dielectric material 1	Er1	FR4	4.00
Dielectric material 2	Er2	FR4	4.00
Plane capacitance 1	C1	µF	0.0550
Plane capacitance 2	C2	µF	0.0080
Total planar capacitance	Ctotal	µF	0.0630
Total sheet resistance	Rtotal	Ω	0.0019

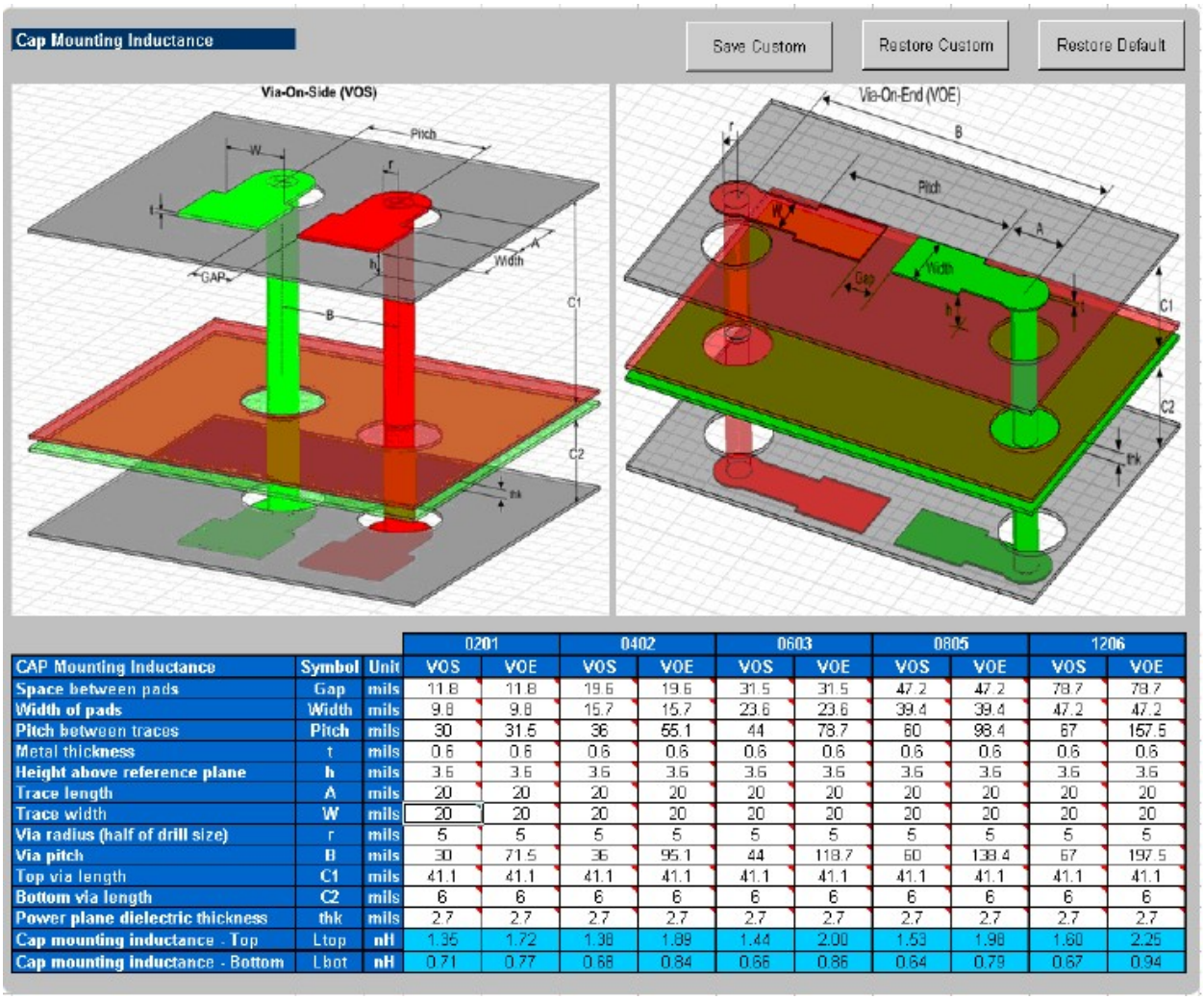
Enter the design specific information such as plane dimensions, plane configuration and the dielectric material used in the **Planar Capacitance** table. The tool calculates a plane capacitance value. You can save custom values, restore custom values, or restore the default settings.

Cap_Mount

The **Cap Mount** tab calculates the capacitor mounting inductance seen by the decoupling capacitor.

Note: Power rails on different layers have different mounting inductances. For the best results, run the PDN separately for each layer set.

Figure 10: Cap Mount Tab



			0201		0402		0603		0805		1206	
CAP Mounting Inductance	Symbol	Unit	VOS	VOE	VOS	VOE	VOS	VOE	VOS	VOE	VOS	VOE
Space between pads	Gap	mils	11.8	11.8	19.6	19.6	31.5	31.5	47.2	47.2	78.7	78.7
Width of pads	Width	mils	9.8	9.8	15.7	15.7	23.6	23.6	39.4	39.4	47.2	47.2
Pitch between traces	Pitch	mils	30	31.5	36	55.1	44	78.7	60	98.4	67	157.5
Metal thickness	t	mils	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Height above reference plane	h	mils	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Trace length	A	mils	20	20	20	20	20	20	20	20	20	20
Trace width	W	mils	20	20	20	20	20	20	20	20	20	20
Via radius (half of drill size)	r	mils	5	5	5	5	5	5	5	5	5	5
Via pitch	B	mils	30	71.5	36	95.1	44	118.7	60	138.4	67	197.5
Top via length	C1	mils	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1
Bottom via length	C2	mils	6	6	6	6	6	6	6	6	6	6
Power plane dielectric thickness	thk	mils	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Cap mounting inductance - Top	Ltop	nH	1.35	1.72	1.38	1.89	1.44	2.00	1.53	1.98	1.60	2.25
Cap mounting inductance - Bottom	Lbot	nH	0.71	0.77	0.68	0.84	0.66	0.86	0.64	0.79	0.67	0.94

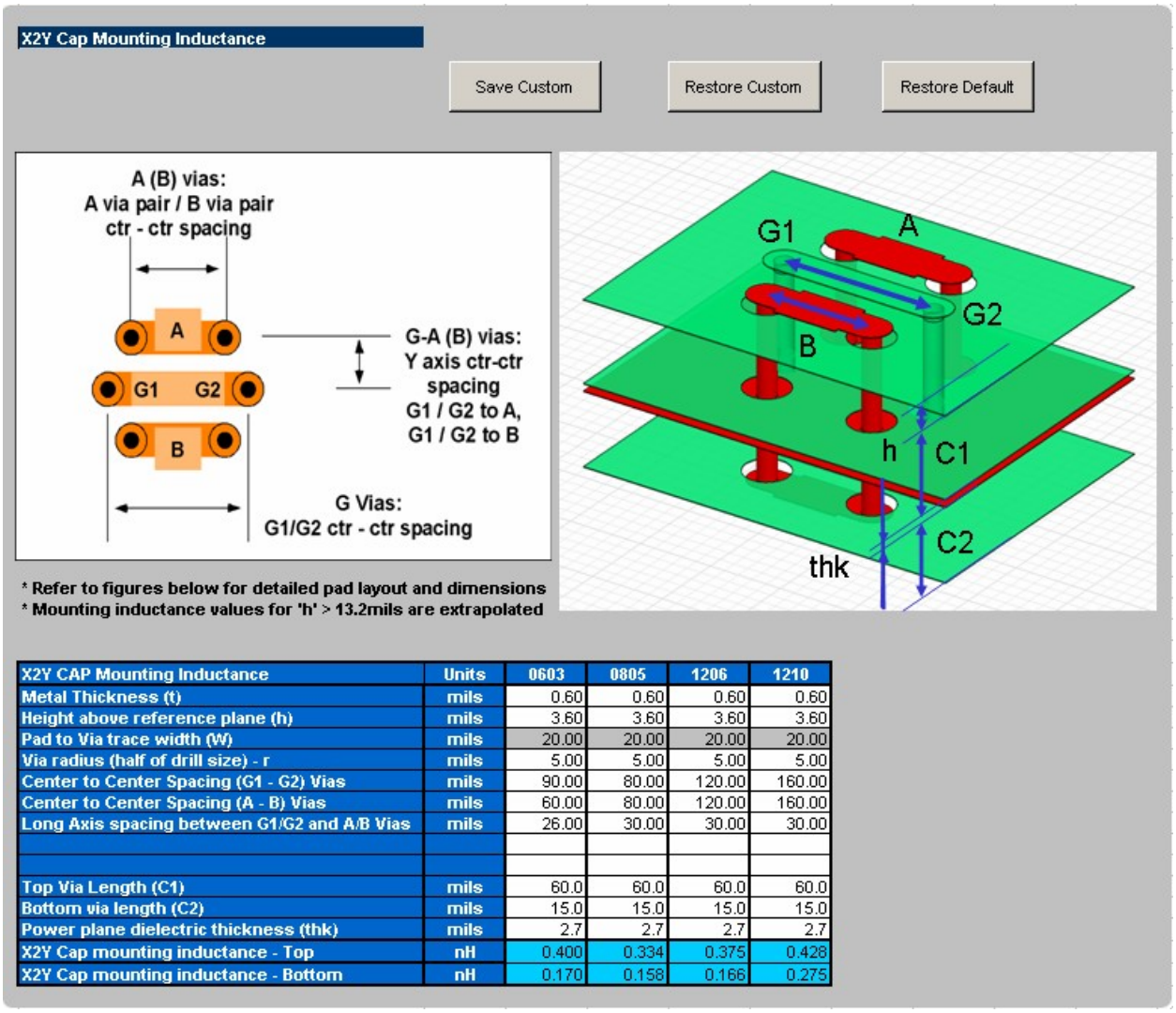
The capacitor mounting calculation is based on the assumption that the decoupling capacitor is a two-terminal device. The capacitor mounting calculation is applicable to any two-terminal capacitor with the following footprints: 0201, 0402, 0603, 0805, and 1206. Enter all the information relevant to your layout, and the tool provides a mounting inductance for a capacitor mounted on either the top or bottom layer of the board. Depending on the layout, you can choose between VOE (Via on End) or VOS (Via on Side) to achieve an accurate capacitor mounting inductance value.

If you plan to use a footprint capacitor other than a regular two-terminal capacitor or X2Y capacitor for decoupling, you can skip the **Cap Mount** tab. In this case, you can directly enter the capacitor parasitics and capacitor mounting inductance in the **Library** tab (under the **Custom** field in the **Decoupling Cap** section of the library). As with the other tabs, you can save the changes made to the tab, restore the changes, or restore the tab back to the default settings.

X2Y_Mount

The **X2Y Mount** tab calculates the capacitor mounting inductance seen by the X2Y decoupling capacitor.

Figure 11: X2Y_Mount Tab



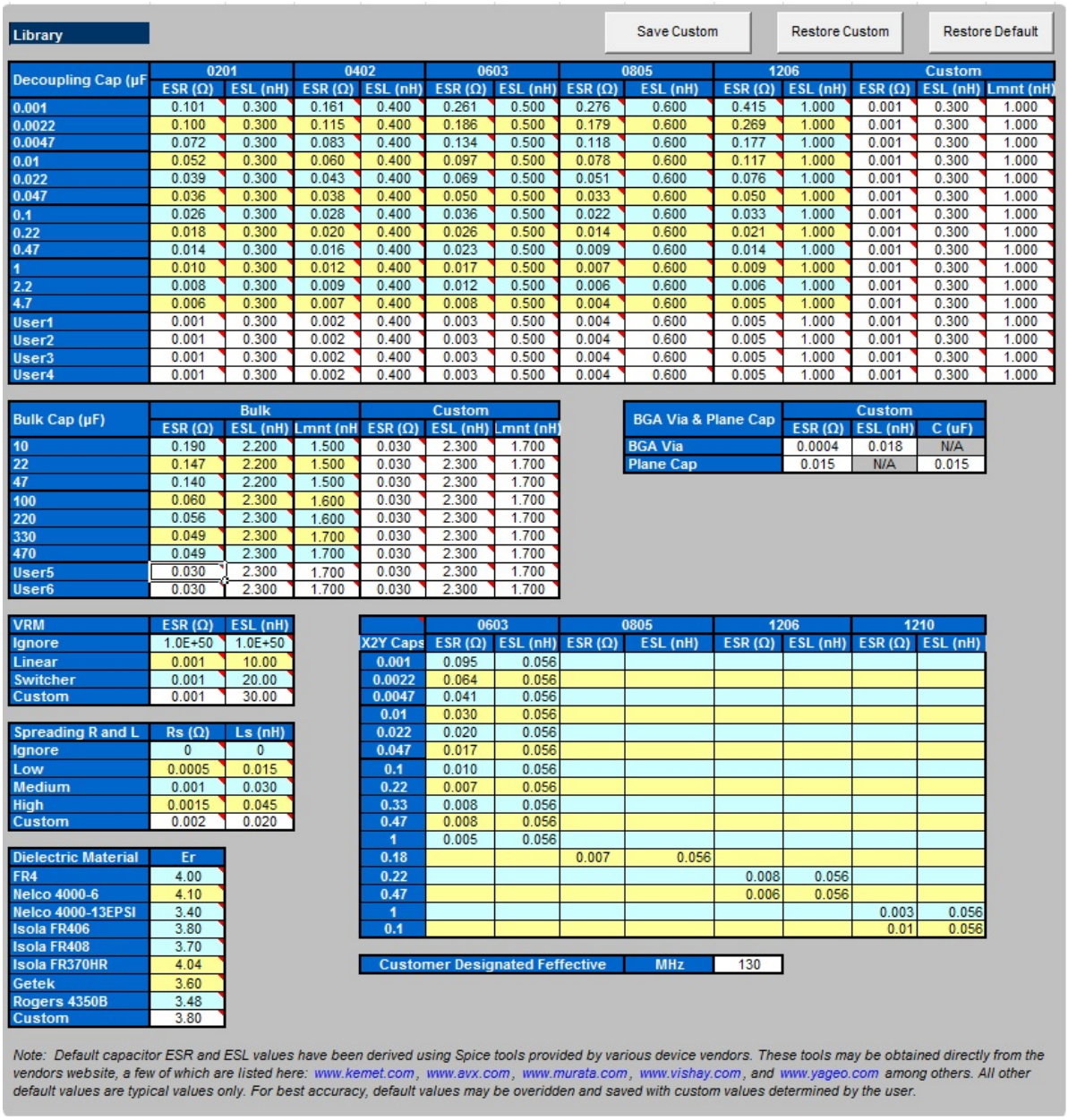
X2Y CAP Mounting Inductance	Units	0603	0805	1206	1210
Metal Thickness (t)	mils	0.60	0.60	0.60	0.60
Height above reference plane (h)	mils	3.60	3.60	3.60	3.60
Pad to Via trace width (W)	mils	20.00	20.00	20.00	20.00
Via radius (half of drill size) - r	mils	5.00	5.00	5.00	5.00
Center to Center Spacing (G1 - G2) Vias	mils	90.00	80.00	120.00	160.00
Center to Center Spacing (A - B) Vias	mils	60.00	80.00	120.00	160.00
Long Axis spacing between G1/G2 and A/B Vias	mils	26.00	30.00	30.00	30.00
Top Via Length (C1)	mils	60.0	60.0	60.0	60.0
Bottom via length (C2)	mils	15.0	15.0	15.0	15.0
Power plane dielectric thickness (thk)	mils	2.7	2.7	2.7	2.7
X2Y Cap mounting inductance - Top	nH	0.400	0.334	0.375	0.428
X2Y Cap mounting inductance - Bottom	nH	0.170	0.158	0.166	0.275

Enter all the information relevant to your layout in the **X2Y CAP Mounting Inductance** table. The tool then provides a mounting inductance for an X2Y capacitor mounted on either the top or bottom layer of the board. You can save the changes made to the tab, restore the changes, or restore the tab back to the default settings.

Library

The **Library** tab stores all the device parameters that are referred to in the other tabs.

Figure 12: Library Tab



Library

Save Custom | Restore Custom | Restore Default

Decoupling Cap (µF	0201		0402		0603		0805		1206		Custom		
	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	Lmnt (nH)
0.001	0.101	0.300	0.161	0.400	0.261	0.500	0.276	0.600	0.415	1.000	0.001	0.300	1.000
0.0022	0.100	0.300	0.115	0.400	0.186	0.500	0.179	0.600	0.269	1.000	0.001	0.300	1.000
0.0047	0.072	0.300	0.083	0.400	0.134	0.500	0.118	0.600	0.177	1.000	0.001	0.300	1.000
0.01	0.052	0.300	0.060	0.400	0.097	0.500	0.078	0.600	0.117	1.000	0.001	0.300	1.000
0.022	0.039	0.300	0.043	0.400	0.069	0.500	0.051	0.600	0.076	1.000	0.001	0.300	1.000
0.047	0.036	0.300	0.038	0.400	0.050	0.500	0.033	0.600	0.050	1.000	0.001	0.300	1.000
0.1	0.026	0.300	0.028	0.400	0.036	0.500	0.022	0.600	0.033	1.000	0.001	0.300	1.000
0.22	0.018	0.300	0.020	0.400	0.026	0.500	0.014	0.600	0.021	1.000	0.001	0.300	1.000
0.47	0.014	0.300	0.016	0.400	0.023	0.500	0.009	0.600	0.014	1.000	0.001	0.300	1.000
1	0.010	0.300	0.012	0.400	0.017	0.500	0.007	0.600	0.009	1.000	0.001	0.300	1.000
2.2	0.008	0.300	0.009	0.400	0.012	0.500	0.006	0.600	0.006	1.000	0.001	0.300	1.000
4.7	0.006	0.300	0.007	0.400	0.008	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User1	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User2	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User3	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User4	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000

Bulk Cap (µF)	Bulk			Custom		
	ESR (Ω)	ESL (nH)	Lmnt (nH	ESR (Ω)	ESL (nH)	Lmnt (nH)
10	0.190	2.200	1.500	0.030	2.300	1.700
22	0.147	2.200	1.500	0.030	2.300	1.700
47	0.140	2.200	1.500	0.030	2.300	1.700
100	0.060	2.300	1.600	0.030	2.300	1.700
220	0.056	2.300	1.600	0.030	2.300	1.700
330	0.049	2.300	1.700	0.030	2.300	1.700
470	0.049	2.300	1.700	0.030	2.300	1.700
User5	0.030	2.300	1.700	0.030	2.300	1.700
User6	0.030	2.300	1.700	0.030	2.300	1.700

BGA Via & Plane Cap	Custom		
	ESR (Ω)	ESL (nH)	C (uF)
BGA Via	0.0004	0.018	N/A
Plane Cap	0.015	N/A	0.015

VRM	ESR (Ω)	ESL (nH)
Ignore	1.0E+50	1.0E+50
Linear	0.001	10.00
Switcher	0.001	20.00
Custom	0.001	30.00

Spreading R and L	Rs (Ω)	Ls (nH)
Ignore	0	0
Low	0.0005	0.015
Medium	0.001	0.030
High	0.0015	0.045
Custom	0.002	0.020

Dielectric Material	Er
FR4	4.00
Nelco 4000-6	4.10
Nelco 4000-13EPSI	3.40
Isola FR406	3.80
Isola FR408	3.70
Isola FR370HR	4.04
Getek	3.60
Rogers 4350B	3.48
Custom	3.80

	0603		0805		1206		1210	
X2Y Caps	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)
0.001	0.095	0.056						
0.0022	0.064	0.056						
0.0047	0.041	0.056						
0.01	0.030	0.056						
0.022	0.020	0.056						
0.047	0.017	0.056						
0.1	0.010	0.056						
0.22	0.007	0.056						
0.33	0.008	0.056						
0.47	0.008	0.056						
1	0.005	0.056						
0.18			0.007	0.056				
0.22					0.008	0.056		
0.47					0.006	0.056		
1							0.003	0.056
0.1							0.01	0.056

Customer Designated Feffective	MHz	130

Note: Default capacitor ESR and ESL values have been derived using Spice tools provided by various device vendors. These tools may be obtained directly from the vendors website, a few of which are listed here: www.kemet.com, www.avx.com, www.murata.com, www.vishay.com, and www.yageo.com among others. All other default values are typical values only. For best accuracy, default values may be overidden and saved with custom values determined by the user.

You can change each of the default values listed in the respective sections to meet the specific needs of your design.

Two-Terminal Decoupling Capacitors

The decoupling capacitors section contains the default ESR and ESL values for the various two-terminal capacitors in the following footprints:

- 0201
- 0402
- 0603
- 0805
- 1206

You also have the option to either modify the default values or enter your own commonly used custom values in the **Custom** field. If you are using a capacitor with a footprint that is not available in the tool, you must use the **Custom** field to enter the capacitor parasitics and the corresponding mounting inductance.

The decoupling capacitors section also provides the option for the user defined capacitors (such as User1,...,User4). You can define the ESR and ESL parasitics for the various footprints and enter the corresponding capacitor value in the **System_Decap** tab. Choose the corresponding footprint when defining the capacitor values.

Bulk Capacitors

The bulk capacitors section contains the commonly used capacitor values for decoupling the power supply at mid and low frequencies. You can change the default values to reflect the parameters specific to the design.

X2Y Decoupling Capacitors

The X2Y decoupling capacitors section contains the default ESR and ESL values for the various X2Y capacitors in the 0603, 0805, 1206, and 1210 footprints. You also can replace the default ESR and ESL values with your own commonly used custom values.

BGA Via and Plane Capacitance

This section allows you to directly enter the values for effective via loop inductance under the BGA and plane capacitance during the pre-layout phase when no design-specific information is available.

If you have access to design-specific information, you can ignore this section and enter the design-specific information in the **Plane Cap** and **BGA Via** tabs that calculate the plane capacitance and the BGA via parasitics, respectively.

VRM Library

The VRM section lists the default values for both the linear and switcher regulators. In the **Custom** field, you can change the VRM parasitics listed under the linear/switcher rows or add the custom parasitics for the VRM relevant to the design.

Spreading R, L Parasitics

This library provides various options for the default effective spreading inductance values that the decoupling capacitors see with respect to the FPGA. These values are based on the quality of the PDN

design. You can choose a **Low** value of effective spreading inductance if you have optimally designed your PDN Network. Optimum PDN design involves implementing the following design rules:

- PCB stackup that provides a wide solid power/ground sandwich for a given supply with a thin dielectric between the planes. This minimizes the current loop, which reduces the spreading inductance. The thickness of the dielectric material between the power/ground pair directly influences the amount of spreading/loop inductance that a decoupling cap can see with respect to the FPGA.
- Placing the capacitors closer to the FPGA from an electrical standpoint.
- Minimizing via perforations in the power/ground sandwich in the current path from the decoupling caps to the FPGA device.

Due to layout and design constraints, the PDN design may not be optimal. In this case, you can choose either a **Medium** or **High** value of spreading R and L. You can also change the default values or use the **Custom** field listed in the library specific to the design.

Dielectric Material Library

This library lists the dielectric constant values for the various commonly used dielectric materials. These values are used in the plane capacitance calculations listed under the **Plane_Cap** tab. You can change the values listed in this section.

If you change the default values listed in the various sections in the **Library** tab, you can save the changes by clicking **Save Custom**. You can restore the default library by clicking **Restore Default** located at the top right-hand corner of the **Library** page. You can also restore the saved custom library by clicking **Restore Custom**.

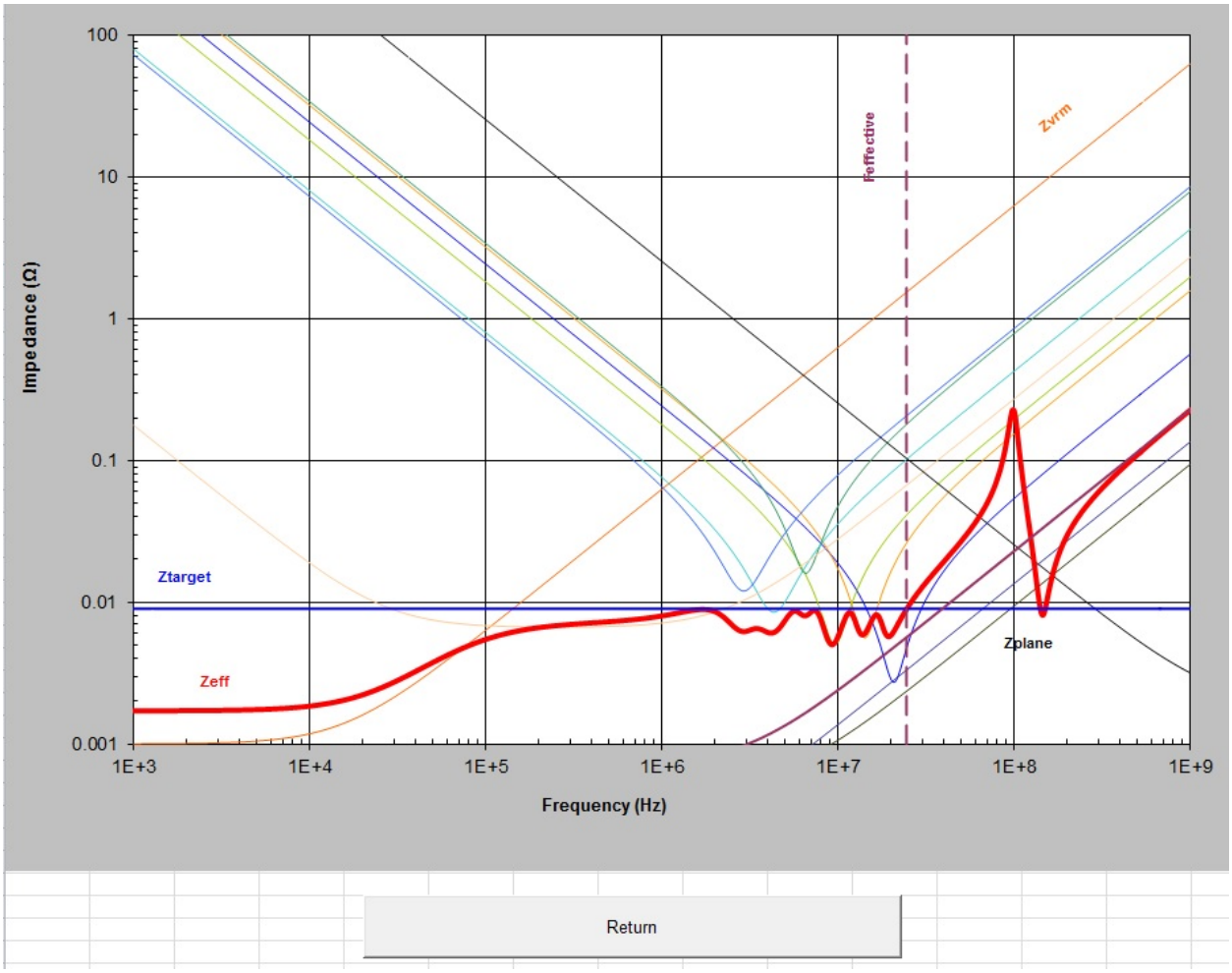
User Set $F_{EFFECTIVE}$

You must decouple to a $F_{EFFECTIVE}$ higher than what is calculated for the power rails of some Altera device families. In this case, you must set the $F_{EFFECTIVE}$ option to **Override** in the **System_Decap** tab. The PDN tool 2.0 then uses the $F_{EFFECTIVE}$ value entered here.

Enlarged_Graph

In the **Enlarged_Graph** tab, you can view the enlarged Z-profile plot. The PDN tool 2.0 switches to this tab when you click on the Z-profile plot in the **System_Decap** tab. You can go back to the **System_Decap** tab when you click the **Return** button.

Figure 13: Enlarged_Graph Tab



Design PCB Decoupling Using the PDN Tool 2.0

PCB decoupling keeps PDN Z_{EFF} smaller than Z_{TARGET} with the properly chosen PCB capacitor combination up to the frequency where the capacitor on the package and die take over the PDN decoupling. This procedure uses the PDN tool 2.0 in different power rail configurations and provides design examples using the Arria 10 device PDN tool.

Pre-Layout Instructions

The PDN tool 2.0 provides an accurate estimate of the number and types of capacitors needed to design a robust power delivery network, regardless of where you are in the design phase. However, the accuracy of the results depends highly on the user inputs for the various parameters.

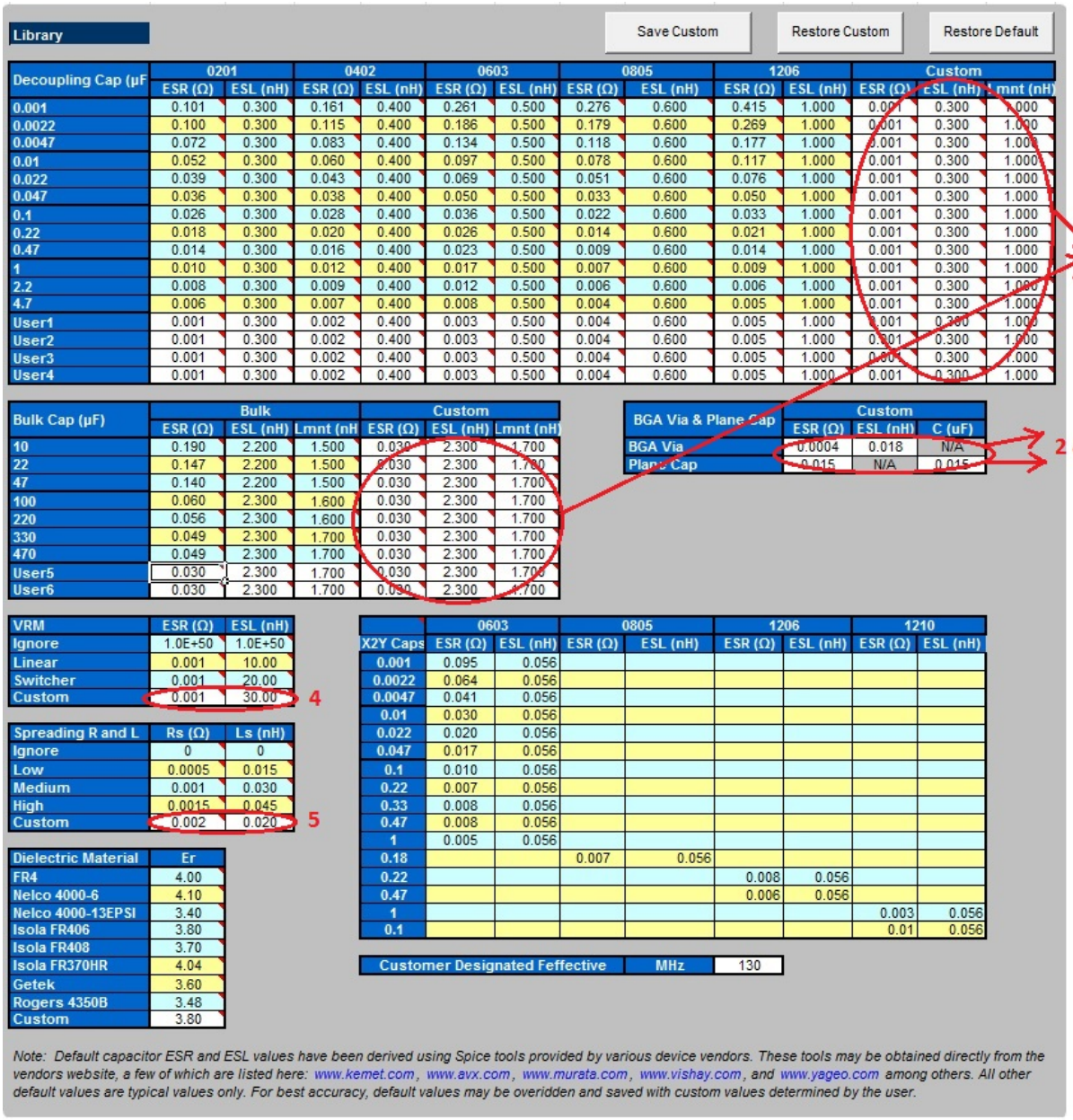
If you have finalized the board stackup and have access to board database and layout information, you can proceed through the tabs and enter the required information to arrive at an accurate decoupling scheme.

In the pre-layout phase of the design cycle when you do not have specific information about the board stack-up and board layout, you can follow these instructions to explore the solution space when finalizing key design parameters such as stackup, plane size, capacitor count, capacitor orientation, and so on.

In the pre-layout phase, ignore the **Plane Cap** and **Cap Mount** tabs and go directly to the **Library** tab when you do not have the layout information. If available, enter the values shown below in the **Library** tab. To use the default values, go directly to the **System_Decap** tab to begin the analysis.

Figure 14: Library Tab Fields

The callouts correspond to the fields in which you must enter values.



Decoupling Cap (µF	0201		0402		0603		0805		1206		Custom		
	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	Lmnt (nH)
0.001	0.101	0.300	0.161	0.400	0.261	0.500	0.276	0.600	0.415	1.000	0.001	0.300	1.000
0.0022	0.100	0.300	0.115	0.400	0.186	0.500	0.179	0.600	0.269	1.000	0.001	0.300	1.000
0.0047	0.072	0.300	0.083	0.400	0.134	0.500	0.118	0.600	0.177	1.000	0.001	0.300	1.000
0.01	0.052	0.300	0.060	0.400	0.097	0.500	0.078	0.600	0.117	1.000	0.001	0.300	1.000
0.022	0.039	0.300	0.043	0.400	0.069	0.500	0.051	0.600	0.076	1.000	0.001	0.300	1.000
0.047	0.036	0.300	0.038	0.400	0.050	0.500	0.033	0.600	0.050	1.000	0.001	0.300	1.000
0.1	0.026	0.300	0.028	0.400	0.036	0.500	0.022	0.600	0.033	1.000	0.001	0.300	1.000
0.22	0.018	0.300	0.020	0.400	0.026	0.500	0.014	0.600	0.021	1.000	0.001	0.300	1.000
0.47	0.014	0.300	0.016	0.400	0.023	0.500	0.009	0.600	0.014	1.000	0.001	0.300	1.000
1	0.010	0.300	0.012	0.400	0.017	0.500	0.007	0.600	0.009	1.000	0.001	0.300	1.000
2.2	0.008	0.300	0.009	0.400	0.012	0.500	0.006	0.600	0.006	1.000	0.001	0.300	1.000
4.7	0.006	0.300	0.007	0.400	0.008	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User1	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User2	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User3	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000
User4	0.001	0.300	0.002	0.400	0.003	0.500	0.004	0.600	0.005	1.000	0.001	0.300	1.000

Bulk Cap (µF)	Bulk			Custom		
	ESR (Ω)	ESL (nH)	Lmnt (nH	ESR (Ω)	ESL (nH)	Lmnt (nH)
10	0.190	2.200	1.500	0.030	2.300	1.700
22	0.147	2.200	1.500	0.030	2.300	1.700
47	0.140	2.200	1.500	0.030	2.300	1.700
100	0.060	2.300	1.600	0.030	2.300	1.700
220	0.056	2.300	1.600	0.030	2.300	1.700
330	0.049	2.300	1.700	0.030	2.300	1.700
470	0.049	2.300	1.700	0.030	2.300	1.700
User5	0.030	2.300	1.700	0.030	2.300	1.700
User6	0.030	2.300	1.700	0.030	2.300	1.700

BGA Via & Plane Cap	Custom		
	ESR (Ω)	ESL (nH)	C (uF)
BGA Via	0.0004	0.018	N/A
Plane Cap	0.015	N/A	0.015

VRM	ESR (Ω)	ESL (nH)
Ignore	1.0E+50	1.0E+50
Linear	0.001	10.00
Switcher	0.001	20.00
Custom	0.001	30.00

Spreading R and L	Rs (Ω)	Ls (nH)
Ignore	0	0
Low	0.0005	0.015
Medium	0.001	0.030
High	0.0015	0.045
Custom	0.002	0.020

Dielectric Material	Er
FR4	4.00
Nelco 4000-6	4.10
Nelco 4000-13EPSI	3.40
Isola FR406	3.80
Isola FR408	3.70
Isola FR370HR	4.04
Getek	3.60
Rogers 4350B	3.48
Custom	3.80

	0603		0805		1206		1210	
X2Y Caps	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)	ESR (Ω)	ESL (nH)
0.001	0.095	0.056						
0.0022	0.064	0.056						
0.0047	0.041	0.056						
0.01	0.030	0.056						
0.022	0.020	0.056						
0.047	0.017	0.056						
0.1	0.010	0.056						
0.22	0.007	0.056						
0.33	0.008	0.056						
0.47	0.008	0.056						
1	0.005	0.056						
0.18			0.007	0.056				
0.22					0.008	0.056		
0.47					0.006	0.056		
1							0.003	0.056
0.1							0.01	0.056

Customer Designated Feffective	MHz	130

Note: Default capacitor ESR and ESL values have been derived using Spice tools provided by various device vendors. These tools may be obtained directly from the vendors website, a few of which are listed here: www.kemet.com, www.avx.com, www.murata.com, www.vishay.com, and www.yageo.com among others. All other default values are typical values only. For best accuracy, default values may be overidden and saved with custom values determined by the user.

1. Enter the ESR, ESL, and Lmnt values for the capacitors listed in the **Custom** field.
2. Enter the effective BGA via (loop) parasitics for the power supply being decoupled in the **BGA Via & Plane Cap** field..
3. Enter the plane capacitance seen by the power/ground plane pair on the board for the power supply in the **BGA Via & Plane Cap** field.
4. Enter the VRM parasitics, if available, in the **Custom** row of the **VRM** field.
5. Enter the effective spreading inductance seen by the decoupling capacitors in the **Custom** row of the **Spreading R and L** field.

Deriving Decoupling in a Single-Rail Scenario

A power supply connects to only one power rail on the FPGA device in a single-rail scenario. The PDN noise is created by the dynamic current change of the single rail. You determine Z_{TARGET} and $F_{EFFECTIVE}$ based on the parameters related to the selected rail only.

The PDN tool 2.0 provides two ways to derive a decoupling network. You can set up the tool with the information needed and let the tool derive the PDN decoupling for your system. You can also manually enter the information and derive decoupling. To derive the desired capacitor combination:

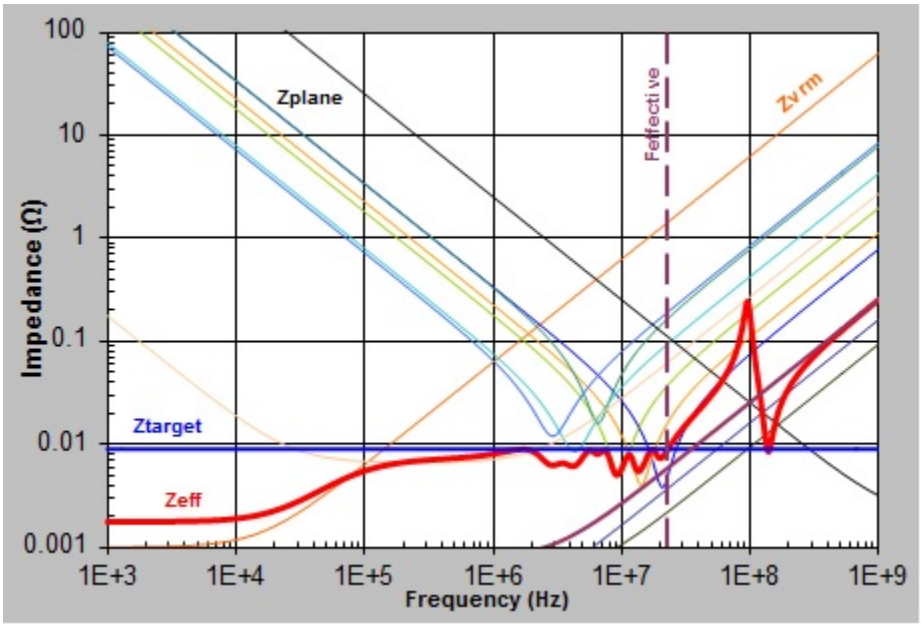
1. Select the device/power rail to work with.
2. Select the parameter settings for the PDN components.
3. Enter the electric parameters to set Z_{TARGET} and $F_{EFFECTIVE}$.
   You need to have a good estimate of the parameters entered to derive the proper decoupling guidelines (Z_{TARGET} and $F_{EFFECTIVE}$). Although you need to determine those guidelines based on the worst-case scenario, pessimistic settings result in hard-to-achieve guidelines and over design of your PCB decoupling.
4. Derive the PCB decoupling scheme.

   You must adjust the number and value of the PCB capacitors in the **Decoupling Capacitor (Mid/High Frequency)** and **Decoupling Capacitor (Bulk)** fields to keep the plotted Z_{EFF} below Z_{TARGET} until $F_{EFFECTIVE}$. You can derive the decoupling for the selected power rail manually. You can also select the **Auto Decouple** button and let the PDN tool 2.0 derive the decoupling scheme. If you are not able to find a capacitor combination that meets your design goal, you can try to change the parameters at **step 2**. For example, you can reduce the BGA via inductance used in the **Calculate** option by reducing the BGA via length in the **BGA_VIA** tab and using the **low** option for plane spreading. These changes reduce parasitic inductance and make it easier to achieve your decoupling goal. To achieve the low spreading setting, you must place the mid to high frequency PCB capacitors close to the FPGA device. You also must minimize the dielectric thickness between the power and ground plane. Refer to *Troubleshooting Z_{EFF}* if the Z_{EFF} is too high or the number of capacitors for decoupling becomes too high.

If you are not able to meet the Z_{TARGET} requirement with the changes above, the PDN in your design may have reached its physical limitation under the electrical parameters you entered for Z_{TARGET} and $F_{EFFECTIVE}$. You should re-examine these parameters to check if they are overly pessimistic.

Figure 15: Enlarged Plot of Z_{EFF}

The design is a decoupling example for a 10AX115R_F40 VCC power rail. Assume that the minimum voltage supply is 0.9 V, I_{MAX} is 10 A, dynamic current change is 50% of I_{MAX}, and the maximum allowable die noise tolerance is 5% of supply voltage. The VCC rail has 50 power BGA vias. The length of BGA via is assumed to be 60 mil.



The PDN tool 2.0 calculated that Z_{TARGET} is 0.0090 Ω and $F_{EFFECTIVE}$ is 22.5 MHz. The figure above shows one of the capacitor combinations that you can select to meet the design goal. As shown in the plot, Z_{EFF} remains under Z_{TARGET} up to $F_{EFFECTIVE}$. There are many combinations, but the ideal solution is to minimize the quantity and the type of capacitors needed to achieve a flat impedance profile below the Z_{TARGET}.

Related Information

Troubleshooting ZEFF on page 27

Deriving Decoupling in the Power-Sharing Scenarios

It is a common practice that several power rails in the FPGA device share the same power supply. For example, you can connect VCCPT, VCCA_PLL, VCCA_FPLL rails that require the same supply voltage to the same PCB power plane. This can be required by the design, such as in the memory interface case. This can also come from the need to reduce bill of materials (BOM) cost. You can use the **System_Decap** tab to facilitate the decoupling design for the power sharing scenarios.

When deriving decoupling capacitors for multiple FPGAs sharing the same power plane, each FPGA should be analyzed separately using the PDN tool 2.0. For each FPGA design, combine the required power rails as described above and analyze the decoupling scheme as if the FPGA was the only device on the power rail, taking note of how the current is divided across the devices.

High frequency decoupling capacitors are meant to provide the current needed for AC transitions, and must be placed in a close proximity to the FPGA power pins. Thus, the PDN tool 2.0 should be used to derive the required decoupling capacitors for the unique power requirements for each FPGA on the board.

The power regulators must be able to supply the total combined current requirements for each load on the supply, but the decoupling capacitor selections should be analyzed on a single FPGA basis.

Troubleshooting Z_{EFF}

When the decoupling mode is set to **Auto**, this may result in a Z_{EFF} value that is too high. This can happen when the PCB parameters you entered result in an inefficient PDN, and the current to be decoupled by the PCB are unrealistically high.

With difficult PCB and current parameters, auto decoupling continues to add decoupling capacitors until it determines they have little effect. This results in hundreds of capacitors. You can achieve decoupling schemes with similar performance manually using far fewer capacitors.

Strategies for Correcting a High Z_{EFF}

As well as decoupling manually, you can reduce the decoupling burden by accurately estimating your current requirements and making your PCB more efficient. You may be able to achieve reduced PCB current requirements in the following ways:

- Estimating realistic current requirements in the Altera Early Power Estimator (EPE).
- Entering realistic toggle rate figures for the logic in the EPE. Unrealistic, high toggle rates dramatically increases dynamic current requirements.
- Entering realistic logic requirements in the EPE.
- Entering realistic clock frequencies in the EPE.
- Using the Quartus II software (Power Play Power Analyzer) PPPA and **.vcd** simulation entry for accurate current requirement estimation.
- Considering Root Sum Squared (RSS) averaging for shared power supply rails. Refer to the **Introduction** tab of the PDN tool for more information on this method.

You can make the PCB more efficient in the following ways:

- Increasing inter-plane capacitance of your Power (PWR) and Ground (GND) plane pair by reducing their dielectric thickness.
- Increasing inter-plane capacitance of your PWR and GND plane pair by increasing their surface area.
- Reducing loop inductance from the PWR and GND plane pair to the FPGA. You can do this by moving them closer to the surface of the PCB where the FPGA is mounted.
- Reducing loop inductance from the high frequency decoupling capacitors to the PWR and GND plane pair. You can do this by placing them on the surface of the PCB that is closest to the planes.
- Using Via On Side (VOS) instead of Via On End (VOE) capacitor mounting topologies to help at high frequencies.
- Using ultra-low Effective Series Inductance (ESL) mounting capacitors to help at high frequencies, for example, X2Y package style.
- Using ultra-low Effective Series Resistance (ESR) bulk capacitors to help at low frequencies.
- Considering larger vias with less ESL.

Realistic tool entry can make decoupling easier to achieve. The following factors affect the calculation of Z_{TARGET}:

- An increase in dynamic current reduces Z_{TARGET} and makes decoupling difficult to achieve. See the guidelines above.
- Enter realistic noise or ripple figures into the PDN tool. Use the noise figure listed in the device and rail specific table in the **Introduction** tab of the PDN Tool. You should not use the DC specification from the device datasheet. Unrealistic ripple requirements reduce Z_{TARGET} and make decoupling difficult.
- Enter realistic transient % figures into the PDN tool. Use the transient % figure listed in the device and rail specific table in the **Introduction** tab of the PDN Tool. Unrealistic transient % requirements reduce Z_{TARGET} and make decoupling difficult.

Document Revision History

Date	Version	Changes
July 2015	2015.07.06	Made the following changes: • Changed the voltage for VCCH_GXB in the "Settings for the Arria 10 Device Power Rails" table.
March 2015	2015.03.06	Made the following changes: • Added MAX 10 to the list of supported devices in the *Overview* section. • Changed the "Device Selection" figure. • Clarified options for entering power supply voltage in the *Power Rail Data and Configuration Section* section. • Changed the "Power Rail Data and Power Sharing Scheme Section" figure. • Added new parameters and descriptions to the *Rail Group Summary Section* section. • Added a note to the *Cap_Mount* section. • Added the *Troubleshooting Z_{EFF}* and *Strategies for Correcting High Z_{EFF}* sections.
September 2014	2014.09.29	• Added notes to the "PDN Topology Modeled as Part of the Tool" figure. • Added detailed explanation of the options availabe in the VRM Impedence pull-down menu in the "VRM Impedence Section."
September 2014	2014.09.12	Initial release.